(54) Title: TREATMENT OF DEAGGLOMERATED PARTICLES WITH PLASMA-ACTIVATED SPECIES

(57) Abstract

A method for treating the surface of substantially each deagglomerated particle of an array of easily agglomerated particles by contacting deagglomerated particles with a plasma-activated gas species and modifying the surfaces of the deagglomerated particles to aid subsequent incorporation of the particles into a matrix composition; the module for deagglomerating and dispersing the particles into the plasma-activated gas; the apparatus that comprises the deagglomeration module (322) and a reaction chamber (20) in which the particles are treated with the plasma-activated gas; the method for deagglomerating particles that may reagglomerate after plasma treatment; and a color composition containing plasma-treated pigment particles.

TITLE

TREATMENT OF DEAGGLOMERATED PARTICLES WITH
PLASMA-ACTIVATED SPECIES

BACKGROUND OF THE INVENTION

5   This invention concerns the atmospheric and subatmospheric
treatment of particulate materials by a plasma-activated gas species to modify the
particle surfaces. U.S. Patent 4,478,643 discloses a pigment treated with a low
temperature plasma wherein the pigment is maintained in a commercially
available plasma asher for a time that is excessive and will cause pigment

10   degradation. U.S. Patent 5,234,723 discloses a process for treating particulates
with a plasma-activated species at subatmospheric pressure by dropping a
particulate through said treatment zone homogeneously. U.S. Patent 5,176,938
discloses a process for treating particulates by passing them through a plasma
flame. U.S. Patent 5,340,618 discloses a method of treating a powder with an

15   atmospheric pressure plasma by dispersing the powder within the reaction
chamber using what appears to be a fluidized bed arrangement without addressing
the problem of deagglomeration.

           The process of the instant invention avoids the harsh treatment
conditions of the '643 and '938 processes and the agglomeration of the '723 and

20   '618 processes.

           The organic particles contemplated for surface modification by the
method of this invention have varying affinities for clumping together as
agglomerates and/or aggregates by virtue of physical and/or chemical attractions
among particles. It is believed that plasma activated species essentially will only

25   interact with, and thereby treat, the surfaces of the clumps. When clumps or
agglomerates are treated, only primary particles that are at or near the surface of
the clump will be treated by the plasma activated species. It therefore follows that
the larger the size of the clump, the smaller the proportion of the primary particles
within the clump that can be treated by the gas species and hence the less effective

30   the treatment process will be.

           There is almost nothing in the prior art to guide one in the
successful implementation of a modification process for materials that readily

agglomerate. In this regard, it has now been discovered that successful surface modification of particles requires an integrated process for deagglomerating clumps of particles and treating them while in their deagglomerated state and before they have an opportunity to reagglomerate. It has been found necessary,

5   for readily clumping particulate materials, to treat the particles while they are in a subdivided state, in order to achieve effective treatment at commercial production rates. The degree to which the clumps are subdivided must be no greater than a certain multiple of the mean dimension of the primary particles. The required conditions for the successful modification of normally clumping particulate

10 organic materials by the process of this invention are as described in more detail hereafter.

SUMMARY OF THE INVENTION

This invention concerns a method for treating the surface of particulate materials that exhibit irreversible degradation when heated above a

15 threshold temperature not exceeding about 500 degrees C with at least one species of plasma-activated process gas in a treatment chamber that contains the plasma source or is downstream of the plasma source, comprising the steps of:

   i   introducing activated process gas into the treatment
chamber,

20   ii   deagglomerating the particles into fractions to expose at
least a portion of the surface of substantially each fraction of
deagglomerated particles,

           iii   contacting the deagglomerated particle fractions with the
activated process gas in the reaction chamber before reagglomeration can

25 occur to any substantial degree,

           iv   modifying at least a portion of the surface of substantially
each deagglomerated particle fraction with the activated process gas, and

           v   controlling the temperature of the deagglomerated particle
fractions so they do not thermally degrade.

30   This invention also concerns a method for grinding agglomerated
pigment particles comprising the steps:

i   disposing to the grinding mechanism agglomerated particles that have been surface-modified by the method of this invention, and

ii   grinding said particles to effect deagglomeration, whereby the deagglomeration is effected at less than about 85% of the time it would take under identical conditions to deagglomerate pigment particles not surface-modified by the method of this invention.

This process will effect size reduction of the agglomerated particles. Wet-milling and high-shear mixing can also be employed in deagglomeration.

This invention also concerns a color composition (color concentrate, millbase, or finished paint) comprising surface-treated pigment particles, the composition having the following properties:

i   viscosity less than one-half that of a like composition comprising untreated particles of the same pigment,

ii   improved tinting strength at least 2% above that of a like composition comprising untreated particles of the same pigment, and

iii   increased pigment to binder ratio at least about 5% above that of a like composition comprising untreated pigment.

It has been found in treating a normally difficult-to-treat pigment, whose color is readily degraded, such as red pigment, that surface treatment can be accomplished by the process of this invention causing a color shift on the $L^*a^*b^*$ color scale of only ±0.3, a color shift less than is observable by the average human observer. As used herein color measurements are expressed in the $L^*a^*b^*$ color space according to ASTM Standards on Color and Appearance Measurement, First Edition, American Society for Testing and Materials (ASTM), Philadelphia, 1984.

This invention also concerns an improvement in an apparatus for treating particles at atmospheric or subatmospheric pressure comprising a reaction or treatment zone in a reaction chamber having particle inlet and outlet means, a plasma-generating source either inside or outside the reaction zone, and a particle storage hopper that cooperates with the inlet. The improvement comprises:

      i   a particle-filled storage hopper designed to operate at a pressure above that of the reaction chamber ;

      ii   a module located between the particle storage hopper and the inlet that cooperates with both, the module comprising means for controlling a feed rate of the particles, for deagglomerating the particles, and for introducing deagglomerated particles into the reaction zone, and

      iii   means for maintaining the deagglomerated particles at a temperature below that at which they degrade.

The apparatus described above will comprise a deagglomeration module that deagglomerates and disperses the particles into the reaction zone characterized by these features:

      i   a mass flow mechanism that moves particles from the hopper to the reaction chamber inlet at a controllable rate of particle mass per unit time, and

      ii   a mechanism for introducing the particles into the reaction zone in a manner to effect particle deagglomeration and dispersion.

It is preferred that the deagglomeration module comprise a mixing chamber for mixing particulates and a carrier gas, mechanical stirring means, an ultrasonic horn energized by an ultrasonic transducer, and an outlet orifice, wherein the pressure in the mixing chamber is maintained above the pressure in the reaction chamber, and wherein the region immediately adjacent the outlet orifice is ultrasonically agitated with sufficient energy to prevent plugging of the orifice by the particles and to facilitate deagglomeration of the particles, the carrier gas then carrying the deagglomerated particles into the reaction chamber. Also contemplated are other means including mechanical deagglomeration and dispersal of the particles with or without the aid of a carrier gas.

This invention also concerns an improvement in an apparatus for treating particles at subatmospheric pressure comprising a reaction or treatment zone in a reaction chamber having particle inlet and outlet means, a plasma-generating source outside the reaction zone, and a particle storage hopper that cooperates with the inlet. The improvement comprises:

      i   a particle-filled storage hopper;

ii   means for controlling a feed rate of the particles from the
storage hopper;

iii   a module located between the particle storage hopper and
the inlet that cooperates with both, the module comprising means for
controlling feed rate of the particles and for deagglomerating the particles,
and introducing deagglomerated particles into the reaction zone; and

iv   means for maintaining the reaction zone at a low plasma
potential.

This invention also concerns an improvement in an apparatus for
treating particles at atmospheric pressure comprising a reaction or treatment zone
in a reaction chamber having particle inlet and outlet means, a plasma-generating
source either inside or outside of the reaction zone, and a particle storage hopper
that cooperates with the inlet. The improvement comprises:

i   a particle-filled storage hopper designed to operate at above
atmospheric pressure ;

ii   a module located between the particle storage hopper and
the inlet that cooperates with both, the module comprising means for
controlling a feed rate of the particles, for deagglomerating the particles.
and for introducing the deagglomerated particles into the reaction zone,
and

iii   means for maintaining the deagglomerated particles at a
temperature below the temperature at which they degrade.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagrammatic block diagram, of the apparatus of the
present invention.

Figure 2 is an elevational view, partly in section, of a first
embodiment of the apparatus of the present invention.

Figure 3 is an elevational view, partly in section, of a second
embodiment of the apparatus of the present invention.

Figure 4 is an enlarged sectional view of the particle feeder
assembly apparatus, corresponding to the second embodiment.

DETAILS OF THE INVENTION

15   PLASMA GENERATION

One skilled in the art will appreciate the numerous ways in which
plasma-activated species contemplated herein may be generated. This invention is
not limited to any particular plasma activation source. On the contrary, any
source can be employed whose use is consistent with the description provided

20   herein. For instance, low pressure plasmas may be energized by microwave
radiation or by radiofrequency radiation; atmospheric pressure plasmas may be
produced by silent discharge or by glow discharge. Typical discharge techniques
are known as "dielectric barrier discharge", "flow stabilized corona", "non-
equilibrium micro-discharge", and the like. An atmospheric pressure glow

25   discharge is achieved by the introduction of an inert gas into the source.
Depending on what is to be accomplished and the nature of the particulate
material to be treated, one or another of these activation sources may be preferred.
Alternative energy sources, such as a DC arc, including the so-called "cascade DC
arc", can also be employed in low pressure activation sources.

30   Since many particulate materials are susceptible to damage when
heated above their threshold temperature, either the treatment zone can be
maintained separate from the plasma creation region, and located further

downstream, or an activated gas species whose temperature is compatible with the
particulate materials, generated by a nonequilibrium atmospheric pressure plasma-
source, can be used.

Particle temperatures and the reactive species concentrations, in the
5   treatment zone can be adjusted by controlling the ratio of the electrical power to
process gas flow rate, or by individually controlling the electrical power, the gas
pressure in the plasma creation region and in the treatment zone, the process and
carrier gas flow rates, the particulate feed rates, and the like.

DESCRIPTION OF TERMS

10   The term "primary particle" employed herein will have a size
determined by the manufacturing process (such as crystallization). The desired
primary particle size is typically determined by the specific end use for which the
particle has been made. For instance, it will be produced to have a certain optical,
mechanical, or chemical property. The minor size dimension of a primary
15   particle will be about 0.01 micron to 10 microns.

"Particle(s)" and "particulate(s)" are particles substantially larger
than primary particle size due to aggregation and/or agglomeration following the
initial manufacturing step of the primary particles.

Materials whose primary particle size is smaller than about 1
20   micron are especially susceptible to agglomeration. Typically, particulate organic
materials are available in the form of particulates that are substantially larger than
the primary particle size. These particulates consist of primary particles bound
together by aggregation and/or agglomeration.

While many particles are approximately spherical in shape, i.e., all
25   three dimensions are about the same, some particles are in the form of fibrils or
flakes. In fibrils, one dimension is significantly larger than the other two. In
flakes, two dimensions are significantly larger than the other one. In the case of
irregularly shaped primary particles, what is contemplated herein are those
particles whose ratio of the arithmetic mean of the three dimensions to the
30   smallest dimension is no greater than about twenty five.

"Aggregates," as the term is used herein, consist of primary
particles that are strongly bound together with chemical bonds at their points of

contact. Aggregates are typically relatively difficult to break apart into primary particles due to the strength of the bonds. Aggregates can contain tens to hundreds of primary particles resulting in particulate materials with effective particle size(s) from about two to ten times larger than the size of the primary particles.

The term "agglomerate(s)," depending on the context, includes primary particles that are associated together, including aggregates, due to interparticle forces such as van der Waals forces, electrostatics, and capillary action. Agglomerates consist of primary particles and possibly aggregates that are weakly bound together at their points of contact. These agglomerates can contain many thousands or millions of primary particles (and possibly many thousands of aggregates), resulting in particulate materials with effective particle size(s) many times larger than the size of primary particles. Generally, agglomerates are larger than aggregates although this is not always the case. The larger the agglomerate, the smaller the proportion of primary particle surfaces that can be treated by the plasma activated gas species and hence the less effective the treatment process will be.

The term "deagglomerated particulate (particle) fraction(s)," or simply "fraction(s)" means particles that result when agglomerated particles are deagglomerated in accordance with the following description. Deagglomerated fractions are generally significantly smaller than the size of the parent agglomerated particles from which the fractions originate, and can range all the way down to primary particle size, depending upon the amount of mechanical energy imparted to the agglomerated particles.

The term deagglomerated fractions is not intended to include primary particles which have been broken or fractured into smaller pieces. More specifically, the process of this invention is intended to treat particle fractions that are no more than about thirty times the average size dimension (arithmetic average or mean) of the primary particle. More preferably, the fraction is no more than twenty times the average size dimension of the primary particle. Most preferably, the fraction is no more than ten times the average size dimension of the primary particle.

By "substantial degree of reagglomeration" is meant that the average particle size has increased to above thirty times the average mean dimension of the primary particle. Particles that exceed about thirty times the average size of the primary particle have been found too large under normal

5   circumstances to be successfully treated by plasma-activated species. The process of this invention excludes the treatment of such overlarge particle clumps.

By "degradation" is meant an undesirable change in one or more properties of the particulate material including discoloration and/or chemical change in which one compound breaks down.

10   By "threshold temperature" is meant that temperature at which degradation begins. A typical example, found in the thermal gravimetric analysis art, is the term onset temperature of decomposition , i. e., the temperature at which the degradation begins, measured by loss of weight (other than loss of solvent) as a function of temperature. This temperature is defined by the

15   intersection of the tangent of the weight percent versus temperature curve before degradation with the tangent of weight percent versus temperature curve during degradation. As contemplated herein, there are two basic modes of treatment of particles: within the zone or region in which the plasma is created, intrasource treatment; and outside the zone or region in which the plasma is created,

20   downstream treatment.

By "plasma potential" is meant the apparent voltage that would be measured by a high impedance voltmeter if one terminal of the voltmeter is connected to the wall of the chamber and the other terminal is placed in the interior volume of the chamber.

25   In the process of this invention, process gas is introduced into a plasma generating zone, where electrical energy is supplied, creating plasma-activated species. This activated gas is then utilized to treat deagglomerated particles, intrasource, or is designed to flow out of this intrasource region to treat such particles downstream.

30   By "downstream" is meant that the particles to be treated do not pass through the plasma creation chamber (or zone or region), but are introduced into a treatment chamber located farther down the path of the already activated

process gas exiting the plasma generation zone. Introduction of particles downstream is typically through an opening or port separate from that through which the plasma-activated species is introduced.

5   As used herein, by "organic compounds" is meant carbon-containing compounds except: binary compounds (such as the carbon oxides, carbides, carbon disulfide, etc.); ternary compounds (such as the metallic cyanides, metallic carbonyls, phosgene, carbonyl sulfide, etc.); and the metallic carbonates (such as calcium carbonate and sodium carbonate), and includes compounds that one skilled in the art would know from The Condensed Chemical

10   Dictionary, 10th edition, revised by Gessner Hawley.

By "introducing activated process gas into the treatment chamber" is meant either introducing already activated process gas into the treatment chamber or introducing process gas into the treatment chamber and then activating it within the treatment chamber.

15   The method of this invention can be operated either at substantially atmospheric pressure, which will be termed "atmospheric" or below atmospheric pressure, which will be termed "subatmospheric". The method can be operated at atmospheric pressure either within the plasma source (intrasource), or in a treatment chamber downstream of the plasma source (downstream). The method

20   can be operated at subatmospheric pressure in a treatment chamber downstream of the plasma source. With respect to both atmospheric and subatmospheric operation of the process of this invention, the particles are deagglomerated while being pneumatically conveyed and dispersed into the treatment zone to maximize the exposure of the surface of each deagglomerated particle to the plasma-

25   activated gas species.

Both the active species concentration and the degree of particle deagglomeration and dispersion are controlled to obtain optimum modification of the particle surface by the activated gas species within the reaction zone of the reactor assembly. The present invention preferably uses conventional reactor

30   materials, which are chemically compatible with the product being treated. If necessary, materials especially resistant to corrosion and wear from the process chemicals can be employed. If needed, liners or surface layers such as

fluoropolymers, quartz, ceramics, silicon oxide, silicon nitride, silicon carbide or synthetic diamond can be employed. The advantages of the present invention include improvement in the dispersion rheology of particles, particularly pigment particles, and offers several potentially valuable benefits including: reduced

5   pigment grind time in manufacturing, lower volatile organic compounds (VOC) in tint, and paints having both higher tinting strength and pigment to binder ratio.

Subatmospheric pressure operation will generally be conducted downstream of the plasma source. With respect to the particle treatment apparatus preferred for use at subatmospheric pressures, the particles that have been surface-

10 treated are typically removed from their storage volume in the bottom of the reaction chamber by an airlock device comprising a double valve arrangement with a storage chamber between the valves, the valves being located serially between the storage volume of the reaction zone and the outlet opening, the apparatus designed to maintain low pressure in the reaction zone when either or

15 both valves are closed, and closure of the valve adjacent to the reaction zone while the valve adjacent to the outlet opening is opened to remove treated particles. During subatmospheric operation of the process of this invention, the plasma-activated reactive gas flows downstream into the separate pigment treatment zone. The plasma potential, specific enthalpy, and heavy species temperature in

20 the treatment zone are controlled at levels that enhance rheology and/or tinting strength, while maintaining critical pigment properties such as color at acceptable levels. Control of the treatment environment can be further facilitated by controlling pressure to below 1 Torr and reducing the temperature of the plasma activated species by use of diffuser plates which also serve to keep the pigment

25 separated from the high temperature plasma creation zone adjacent to the microwave source.

Although a diffuser plate assembly is preferred to disperse the plasma-activated species and to prevent thermal degradation of the particles in the treatment zone, other equivalent mechanisms are contemplated, such as a

30 serpentine gas passage or the addition of a quench gas to quench the plasma. In a preferred embodiment, particles exiting a conventional volumetric solids feeder enter a deagglomeration module which comprises, a mixing chamber, a motor

driven agitator, a means for injecting a controlled amount of carrier gas through a porous plate, an ultrasonically activated orifice (e.g... Branson Vacuum horn # 109-017-215), driven by an ultrasonic transducer, (e.g., Dukane transducer # 41C27), powered by a power supply (e.g., Dukane power supply # 20 A 1000).

5   Upon entering the mixing chamber, the particles are partially deagglomerated by the agitator and mixed with carrier gas. As the particles become aerated by the carrier gas flowing through the porous plate they are drawn toward the lower pressure area of the orifice.

               The ultrasonic horn to which the orifice is mounted generates
10   acoustic waves which are transmitted via the gas into the chamber. This acoustic energy combined with the mechanical motion of the horn is of sufficient intensity to deagglomerate the particles. As the particles move closer to the orifice, the intensity of this acoustic energy increases and an increasing degree of deagglomeration is effected. The strongest deagglomerating force induced by the
15   ultrasound is present in the vicinity of the orifice and while readily agglomerated particles would normally tend to build-up and obscure the orifice, the combination of the ultrasonically-induced mechanical motion of the orifice and the large deagglomerating acoustic forces in the vicinity of the orifice deter such a tendency. The particles are then drawn through the ultrasonically vibrated orifice
20   and passed through the center of the ultrasonic horn which is connected to a transfer line leading to an input port on the reactor. As the particles are accelerated from the higher pressure regime in the mixing chamber to the lower pressure regime in the reactor, gas entrained in the particles at higher pressures will provide additional deagglomerating forces as will collisions at the higher
25   speeds. To function in this mode, this embodiment requires: (a) that the pressure drop between the particles feed hopper and the mixing chamber be minimal; (b) that there is a sufficient pressure drop between the mixing chamber and the reactor to accommodate the conveyance of the solid by the motion of the injected gas; and (c) that the pressure in the mixing chamber be sufficient so that the ultrasonic horn
30   is efficient in conveying acoustic energy into the mixing chamber (i.e., >500 Torr).

To control the relative pressures between the two regimes: (a) a controlled amount of gas is injected into the mixing chamber so as to match the amount fed through the orifice and (b) the orifice is appropriately sized. The orifice is typically circular in shape with a diameter in the range of about 0.2 mm

5   (0.008 inches) to 3.0 mm (0.120 inches), preferably in the range of about 0.5 mm to 2.0 mm. The size of the orifice is selected according to the rate at which the particles are fed into the treatment apparatus and according to the gas pressure utilized.

The combination of orifice size and relative pressure between the

10   mixing chamber and the reaction chamber constitute a "mass flow mechanism" that moves particles from the hopper to the reaction chamber inlet at a controllable rate of particle mass per unit time. The combination of motor-driven agitator, ultrasonic energizing of the region adjacent the orifice and the pressure experienced by the gas-particle mixture between the mixing and reaction

15   chambers constitute a mechanism for introducing the particles into the reaction zone in a manner to effect particle deagglomeration and dispersion.

It is a feature of all embodiments of this invention that deagglomeration can be accomplished by one or a combination of mechanical means, ultrasonic vibration, electrostatic means, and the throughput of carrier gas.

20   The preferred process, where the particles being treated are pigment particles, will create an effective residence time of the particles with the activated species of less than about 2 seconds. A primary benefit of the process of this invention is that particulate behavior can be modified to effect desirable changes in surface properties without causing irreversible degradation. It is important in the

25   successful practice of this invention to treat as many of the primary particles contained within the agglomerates as possible. It is equally important to control the temperature of the particles so that the threshold temperature of the particular material being treated will not be exceeded. Each material to be treated has a threshold temperature that can be predetermined, either from the literature, e.g.,

30   from its reported Tg value, or can be determined by experimentation. Of special interest is the treatment method in which the particles are pigment particles.

When the particles to be treated are pigment particles, it is preferred to maintain the temperature of the particles below that at which a pigment color shift will occur. Pigment particles are treated by the process of this invention to functionalize their surfaces to complement the pigment dispersant
5   thus enhancing the long term stability of the resulting color compositions. Additional properties of the resulting color composition affected by surface treatment include enhanced rheology, minimization of color drift, improved tint strength and hiding, as well as more efficient dispersibility in the coating binder.

The process of this invention can be operated as a batch or
10   continuous process. In a continuous process the particles can be treated in a continuous manner and removed from the reaction chamber in a discontinuous manner or in a continuous manner. Yet another feature is dispersing the deagglomerated particles in the reaction chamber in the presence of a carrier gas. The carrier gas can be the same or different from the process gas. The process gas
15   is the gas from which the activated species are produced by the activating plasma. It is contemplated that more than one carrier gas and/or more than one process gas can be employed. It is not always necessary to employ an inert gas in the operation of this process, although this can be done if desired. Use of an inert gas, such as helium, is preferred in the downstream atmospheric pressure embodiment.
20   Contemplated process and carrier gases will depend on the nature of the particulates being treated, on the method of treatment (atmospheric or subatmospheric), and the surface modification desired. As discussed in more detail hereafter, process gases can be selected from oxygen, nitrogen, water vapor, hydrogen peroxide, carbon dioxide, ammonia, ozone, carbon monoxide,
25   trimethylsilane, tetraetoxysilane (TEOS), hexamethyldisiloxane, ethylene diamine, maleic anhydride, arylamine, acetylene, methane, ethylene oxide, hydrogen, styrene, air, sulfur dioxide, sulfonyl precursors, phosphonyl precursors, alcohols and includes inert gases such as helium and argon. Carrier gases can be selected from the named process gases. Under certain process conditions, when
30   activation of the process gas produces short-lived activated species, particularly where atmospheric pressure treatment is effected in a downstream embodiment, it is preferred to employ an inert gas, particularly helium, to assure availability of

activated species in the reaction zone. In addition, it is cost-effective and thus desirable to recycle the process and/or carrier gases as will be discussed in more detail hereafter.

Representative features of the apparatus and method(s) of the low

5 pressure embodiment of this invention include the use of diffuser plates to disperse the activated gas species, reduce the presence of charged species and lower the maximum energy density in the reaction chamber. The use of diffuser plates assures that the plasma potential does not exceed about 1 volt. Contemplated system pressure will typically not exceed about 10 Torrs with

10 preferred pressures being no more than about 1 Torr.

Figure 1 is a diagrammatic block diagram, of the apparatus of the present invention. All embodiments comprise similar elements, but arranged in different ways. The apparatus comprises a plasma source 1, having an associated power supply, 1S, and a reactor assembly, 2. In a first embodiment, a feeder

15 assembly, 3, comprising a feeder, 3F, and a deagglomeration module, 3D, introduces deagglomerated particles into a reaction zone, 2Z, of reactor, 2. In a second embodiment, a feeder assembly, 3', comprising a feeder, 3F', and a deagglomeration module, 3D', introduce deagglomerated particles into the plasma creation zone, 1Z, which in this embodiment is common with the reaction zone,

20 2Z. A collection assembly, 4, collects the treated particles. A gas removal assembly, 5, comprising a gas/particle separator, 6, and a gas moving device, 7, removes the gas and residual gas-entrained particles from the reactor assembly, 2. The gas moving device, 7, can take the form of a vacuum pump or a fan unit.

Figure 2 depicts a first embodiment of the apparatus of this

25 invention, comprising a system control unit, 12, a reactor assembly, 20, a microwave plasma generator, 40, a particle feeder assembly, 50, a particle collection assembly, 70, a particle separator assembly, 80, a vacuum pump assembly, 90, a source of process gas, 100, associated filter, 102, associated mass flow controller, 104, a source of carrier gas, 110, associated filter, 112, associated

30 mass flow controller, 114, a source of cooling water, 120, and a source of pressurized air, 130. The system control unit, 12, which can be any conventional control unit such as a programmable controller, monitors process conditions via

pressure transducers, 14, 16, mass flow controller flow signal outputs, 104S, 114S, and controls process parameters via control signals, 17, 18, 104C, and 114C. The reactor assembly, 20, is a generally cylindrical structure comprising a plurality of flanged tube sections, 22, 24, and a Y-shaped flanged section, 26. The

5   Y-shaped section, 26, comprises an appendage, 26A, and a storage volume, 26V.

Suitable seals, 30, (best seen in Figure 5) which can comprise gaskets or O-rings, are employed at all flange connections throughout the apparatus to render the apparatus vacuum tight when assembled. The microwave plasma generator, 40, is a commercially available assembly comprising a Model

10   AX2115-2 microwave power generator,40G, a Model AX3120 circulator, 40C, with a Model AX3030 dummy load, 40L, a Model AX3045 automated microwave tuner, 40T, and a Model AX7020 downstream plasma generator, 40P, all available from Applied Science and Technologies (ASTeX), Inc. of Woburn, MA. One or more vortex coolers, 132, can be optionally used to cool the plasma generator,

15   40P. An optional diffuser assembly, such as shown in Figures 5 and 6, can be employed to reduce the temperature of and better distribute the process gas in the reaction zone, 20R, of reactor assembly, 20. The particle feeder assembly, 50, comprises a Model KW2MV-T35 screw feeder, 306, equipped with a 3.5 cubic foot conical hopper, 308, fitted with a bridge breaker (rotary stirrer), 310, from K-

20   TRON North America of Pitman, NJ. Stirrer assembly, 310, is driven by an external drive motor assembly, 60. The screw feeder mechanism, 306, driven by motor, 312, can be used to convey partially agglomerated particles to diffusion manifold, 320, and deagglomerating/ dispersing mechanism, 322, which feeds reactor, 20. The particle collection assembly, 70, comprises an airlock collection

25   assembly, 74, which comprises chambers, 76, 78 and valves, 77, 77`, and facilitates removal of treated product from the reactor assembly, 20, into a receiving container, 400, by conveying means, 402, without interruption of the treatment process. The particle separator assembly, 80, comprises a cylindrical filter housing, 82, which holds a suitable filter, 82F, such as a cartridge or bag

30   filter, and a flanged pipe assembly, 84, having a side port, 84P1. A filter shaking mechanism, 82S, driven by motor, 82M, can be used to periodically shake accumulated particles from filter, 82F. A pressure sensor, 14, is connected to the

port, 84P1, to monitor the pressure on the vacuum pump side of the filter in the filter housing. Pipe assembly, 88, connects the separator assembly to the appendage, 26A, of Y-shaped section, 26, of reactor assembly, 20.

The vacuum pump assembly, 90, can comprise any suitable
5   commercially available vacuum pump, such as a Model E2M40 in combination with a Model EH1200 mechanical booster pump from Edwards High Vacuum International of Wilmington, MA and is connected to particle separator assembly, 80, by a suitable pipe, 92, typically with commercially available vacuum apparatus flange connections. Valve, 84V, can be used to isolate the separator
10 assembly, 80, from the vacuum pump, 90, as needed. The apparatus of Figure 2 is useful to operate a continuous process. Particulates are conveyed from an open container, 300, via pneumatic (or other) means, 302, to the feeder assembly, 50. Optional vent, 220, and filter, 230, can be used when pneumatic conveying means are used to insure that particulates do not escape into the atmosphere. The
15 particles form a vacuum seal allowing feeding of particles in continuous process mode. The rotary stirrer, 310, driven by motor, 60, is provided in the hopper to avoid loss of vacuum seal via flow induced channels opening to the atmosphere. Feed from the feeder assembly, 50, to reactor inlet includes mass flow control via a transfer line, 213, and diffusion manifold, 320, wherein carrier gas from mass
20 flow controller, 114, is mixed with the particulate(s) forming a fluidized mixture which can be more finely divided via a deagglomerating/dispersion mechanism, 322, at the reactor inlet. Carrier gas utilization is minimized to lower vacuum/filter requirements. The mixture of carrier gas and particles enter the reaction chamber at high velocity. The expansion of the carrier gas as the mixture
25 enters the reaction chamber further disperses the particles. Some deagglomerated particles impact the wall of the reactor assembly and their momentum causes them to break apart and form a cloud of highly dispersed particles in the volume of the reaction zone.

After treatment, product falls to the bottom of the reactor into the
30 collection assembly, 74, for subsequent removal from the reactor assembly vessel to a receiving container, 400, at atmospheric pressure. The chamber, 78, is periodically emptied while chamber, 76, continues to receive treated product, thus

effectively removing treated particles from the reaction chamber continuously.
The particulate-containing gas stream which flows toward the vacuum pump is
then filtered by filter assembly, 80, to remove pigment particles which are
returned internally to the collection assembly upon filter cleaning, by shaker, 82S,
5   to maximize yield of product. The upward angle of the appendage, 26A, of the Y-
shaped section, 26, is preferably inclined at an angle between 45 and 60 degrees
above the horizontal to minimize the amount of residual particles which reach the
filter assembly.

It is known in the art that radical generation in the activated gas
10 species in a downstream plasma generator can be optimized by cooling the quartz
tube within the plasma generator and by insuring the quartz tube has an ultra-
smooth surface finish. The quartz tube is typically cooled using vortex tubes such
as Model 10604-H from ITW Vortec of Cincinnati, OH and can be periodically
smoothed using a hydrogen fluoride (HF) etch. See, for example, Thissell,
15 Process and Control of Selective Area Laser Deposition from Methane and
Hydrogen, Ph.D. Dissertation, University of Texas at Austin, December 1994.

Figure 3 depicts a second embodiment of the apparatus of this
invention comprising a system control unit, 12, a reactor assembly, 20, a
microwave plasma generator, 40, a particle feeder assembly, 50', a particle
20 collection assembly, 70, a particle separator assembly, 80, and a vacuum pump
assembly, 90, a source of process gas, 100, associated filter, 102, associated mass
flow controller, 104, a source of carrier gas, 110, associated filter, 112, associated
mass flow controllers, 115, 117, a source of cooling water, 120, and a source of
pressurized air, 130.

25 The system control unit, 12, which can be implemented by any
conventional control unit such as a programmable controller, monitors process
conditions via transducers, 14, 16, and controls process parameters via control
signals, 17, 18, 104C, 115C, 117C. The reactor assembly, 20, similar to that of
Figure 2, is a generally cylindrical structure comprising a plurality of flanged pipe
30 and tube sections, 22, 24, a Y-shaped flanged section, 26, and end cap, 25. The
pipe section, 22, has a plurality of threaded side ports, 22P1, 22P2, 22P3; see
Fig. 5. The microwave plasma generator, 40, is a commercially available

assembly such as described in conjunction with Figure 2. An optional diffuser assembly can be used, as previously discussed. The particle feeder assembly, 50', best seen in Figure 4, comprises a particle feed hopper from Metco Inc. of Westbury, NY which has been modified.

5   The particle collection assembly, 70, comprises a collection container, 72. Collection container, 72, typically flanged for vacuum-tight attachment to the reactor assembly, is used for a batch mode of operation, requiring the reactor to be returned to atmospheric pressure while the collection container is removed and emptied of treated product.

10   The particle separator assembly, 80, comprises a cylindrical filter housing, 82, which holds a suitable cartridge filter, 82F, such as an expanded PTFE membrane cartridge, sold under the trade name GoreTex Light Pulse filter cartridge available from W. L. Gore & Associates, Inc. of Elkton, Maryland, and a flanged pipe assembly, 84, having side ports, 84P1 and 84P2. A pressure sensor,

15   14, is mounted on one side of port, 84P1, to monitor the pressure in the filter housing. A valve, 15, one side of which is open to the atmosphere, can be connected to port, 84P2, and is typically used to momentarily back pulse the filter cartridge, 82F, to remove accumulated particles. Pipe assembly, 88, connects the separator assembly to Y-shaped pipe section, 26, of reactor assembly, 20. The

20   vacuum pump assembly, 90, can comprise any suitable commercially available vacuum pump, such as described in conjunction with Figure 2 and is connected to particle separator assembly, 80, by a suitable pipe, 92, typically with commercially available vacuum apparatus flange connections.

           Figure 4 depicts the particle feeder assembly, 50', modified to

25   relocate the gas inlet assembly, 52, to remove the powder pickup tube and reduce the area of the powder aeration plate, 58, to incorporate the addition of a stirrer assembly, 54, one or more ceramic balls, 56, and a particle screen assembly, 203. Stirrer assembly, 54, is driven by an external drive motor assembly, 60. Mass flow controller, 115, supplies carrier gas to inlet port, 209, through valve, 116.

30   Mass flow controller, 117, distributes carrier gas to inlet ports, 210, 211, of feeder assembly, 50' through valve, 118. Particles are loaded into the reservoir, 205, onto screen assembly, 203, through hopper-top, 201, which is secured by clamp

assembly, 202. Particles sit on screen assembly, 203. The agitator assembly comprises one or more bridge breakers, 204, one or more bridge breaker sweepers, 200, screen, 203, agitator balls, 56, and drive shaft assembly, 206. The agitator assembly is connected to motor, 60, by a flexible drive shaft, 207. Upon initiation of the feed cycle, the following events occur simultaneously. Valves 116, 118, 119 (see Fig. 3), open. Valve, 116, fed by mass flow controller, 115, in the carrier gas line opens allowing carrier gas to enter feeder assembly, 50, via port, 209. Valve, 118, fed by mass flow controller, 117, in the carrier gas line opens allowing carrier gas to enter feeder assembly, 50, via aeration ports, 210, and 211. Bridge breakers, 200, 204, move particles away from and down along the interior walls of the hopper reservoir, 205. The sweepers, 200, move across the screen assembly, 203, interacting with the balls, 56, breaking and sieving the agglomerated particles. The balls, 56, also move vertically, rolling over the sweepers, 200, and colliding with the screen, 203, clearing particles from the screen and increasing the sieving action. Partially deagglomerated particles sieve through the screen where fluidizing action of the gas entering at 211 causes further deagglomeration. Valve, 119, between hopper and reactor, opens to allow the gas and particles in the area, 50L, to be pneumatically dispersed into the reactor. Flow control is further aided by pneumatically vibrating the hopper assembly, powered by pressurized air, 130.

Particles are deagglomerated and dispersed by simultaneous action of the following: mechanical stirring with ceramic balls and sieving through screen assembly; controlling the pressure difference between the upper particle reservoir, 205, and the lower region, 50L; providing sufficient carrier gas through ports, 210 and 211, to provide sufficient mechanical energy to fluidize particles in the lower portion, 50L, of hopper and transfer particles into the reaction chamber without inhibiting overall reduced pressure in the treatment system. Pressure difference between reactor and 50L region will cause fluidized and partially deagglomerated particles to enter transfer line, 213, where they are pneumatically conveyed and accelerated toward the reactor. This rapid acceleration causes high speed collisions of the particles among themselves and with transfer line walls and the carrier gas to effect further deagglomeration. Another deagglomeration/

dispersion mechanism, 322, as in Figure 2, can be employed if desired. Particles enter reactor, 20, through nozzle assembly, 22N (Fig. 5), while moving at high velocity leading to collision with the opposite reactor wall. Other types of dispersing targets can be employed as will be obvious to one skilled in the art.

5   The result is a dispersion rapidly flowing throughout the reactor volume.

Figure 5 depicts the reaction chamber area including the inlet for the deagglomerated particulates which are dispersed under system pressure to effect any residual deagglomeration that may be necessary. Also shown is one assembly, 44, of diffuser plates to distribute the activated gas species and to

10   attentuate plasma potential and protect the particles from the most energetic plasma region. Any equivalent diffuser mechanism, 44, can be employed which accomplishes this effect. There can be as few as one plate in any orientation located between the plasma and the bulk of the particles being introduced into the reaction chamber. The plates can be of any slope and design pattern to effect this

15   result.

In Figure 6, the three diffuser plates referenced in Figure 5 are shown. The diffuser plates are commonly constructed from quartz, which is a material benign to the process and beneficial to the flow of the desired radical-rich stream of activated gas species. The top diffuser plate, 46 (Fig. 6A), is oriented

20   below the opening of the ASTeX downstream plasma generator at a sufficient distance to allow the plasma stream to cool to prevent melting the quartz plate. The center of the top diffuser plate, 46, is removed to allow the high velocity, high energy gas species to enter a series of diffuser plates with offset openings or paths for the gas species to increase the number of collisions between the plasma

25   constituents and the plasma-compatible diffuser plates during their migration toward the particles to be treated. The increased collisions of the gas species induce recombination of the ions with the electrons, leaving a radical-rich stream for interaction with the particles to be treated. Quartz is typically used to construct the offset paths for the diffuser plates to maintain the radical-rich

30   stream, but other materials benign to the process and compatible with the activated process gas can be used. In addition, the holes cut into the bottom diffuser plate, 48 (Fig. 6C), are progressively smaller in diameter for the center

line of the structure than those in the upper diffuser plates. 46 and 47 (Fig. 6B), to maximize the number of collisions between ions and electrons to optimally create a radical-rich stream and to minimize the possibility of backstreaming of particulates being treated.

5   Figure 7 depicts a simplified view of a third embodiment of the apparatus of this invention, similar in many ways to the first and second embodiments. This embodiment utilizes a particle feeder assembly, 50', which incorporates a deagglomeration module, 500, a particle collection assembly, 70', a particle separator assembly, 80', and a vacuum pump assembly, 90. For

10   simplicity of illustration, some elements common to the earlier embodiments are not shown. The reactor assembly, 20, which is essentially the same as that shown in Figure 2, is shown in a simplified form. The particle feeder assembly, 50', is similar to that shown in Figure 2. The screw feeder mechanism, 306, driven by motor, 312, conveys agglomerated particles to the deagglomeration module, 500,

15   which feeds reactor, 20. The particle collection assembly. 70', comprises a chamber, 476, a valve 477, a screw feeder mechanism, 456, driven by motor, 462, and a pneumatic conveying assembly, 402, which facilitates removal of treated product from the chamber, 476, into a receiving container, 400, without interruption of the treatment process. The pneumatic conveying assembly, 402,

20   comprises a source of conveying gas, 404, such as nitrogen, a first valve, 406, a second valve, 408, a vacuum pump, 410, a filter assembly, 412, line ,414, a transfer line, 416, a third valve, 418, a filter assembly, 420, a fourth valve, 422, and a fifth valve, 424. The particle separator assembly, 80', is similar to separator assembly 80, with the addition of a cyclone separator, 481, and

25   associated collection container, 481C. The cyclone separator, 481, removes most of the particles from the particulate-containing gas stream which flows toward the vacuum pump, 90. This reduces the number of particles loading the filter, 82F, and thus minimizes the pressure drop across the filter, 82F. The relatively small quantity of pigment particles collected in container, 481C, can be manually

30   removed or conveyed by mechanical means to the receiving container, 400. One or more optional diffusion plates, as indicated by reference numeral, 548, similar

to diffusion plates, 46, 47, 48, described in conjunction with Figure 5, may be
used to prevent the particulates from entering the plasma source, 40.

The apparatus of Figure 7 is useful to operate a continuous process.
Particulates are conveyed from an open container, 300, to the feeder assembly,
5   50', as described in conjunction with Figure 1. Feed from the conical hopper,
308, to the deagglomeration module, 500, is controlled by a screw feeder, 306.
The deagglomeration module, 500, receives the agglomerated particles, mixes
them with carrier gas, passes them through the ultrasonically agitated orifice, 514,
(best seen in Figure 11) where the particles are deagglomerated and then fed to the
10   reactor, 20. Carrier gas utilization is controlled by the size of the orifice, 514, to
minimize the vacuum pump/filter requirements while maintaining the particles in
a deagglomerated state. The mixture of carrier gas and particles enter the reaction
chamber, 20, at high velocity. The expansion of the carrier gas as the mixture
enters the reaction chamber disperses the particles and forms a cloud of highly
15   dispersed particles in the volume of the reaction zone. Some deagglomerated
particles impact the wall of the reactor assembly and their momentum causes them
to break apart to a greater degree. After treatment, product falls to the bottom
volume, 20V, of the reactor, 20, and into chamber, 476, through valve, 477, which
is normally kept open. The chamber, 476, is periodically emptied into the
20   receiving container, 400, at atmospheric pressure. Valve, 477, is closed and
chamber, 476, is emptied while the bottom volume, 20V, of the reactor, 20,
continues to receive treated product. Valve, 477, is then opened, thus effectively
removing treated particles from the reaction chamber continuously.

When the level of the particles in the chamber, 476, has reached a
25   predetermined level an emptying cycle is initiated. At the start of a cycle, just
after valve, 477, has closed, valves 406, 418 are in a closed state. Valve, 408,
which was open to permit vacuum pump, 410, to evacuate chamber, 476, to the
same low pressure level of the reaction chamber, 20, is then closed. Valves ,406.
418, are opened and motor, 462, is energized to cause screw feeder, 456, to feed
30   particles to the output port of chamber, 476, to transfer line, 416. Gas source, 404,
causes conveying gas to flow through line, 414, into chamber, 476, and causes the
particulate-containing gas stream to flow through 416, toward the receiving

container, 400. Valve, 424, is open, allowing excess gas to vent through filter
assembly, 420, to the atmosphere. When chamber, 476, is empty, valves, 406 and
418, are closed and valve, 408, is opened, permitting vacuum pump, 410, to again
evacuate chamber, 476, to the same low pressure as reactor, 20. Valve, 477, is
then opened. Periodically, filter, 420, can be cleaned of accumulated particles by
back pulsing the filter with a short burst of gas by opening valve, 422, for a short
period of time.

The apparatus of Figure 7 can be utilized to modify thermally
sensitive deagglomerated particle surfaces, such as organic powder surfaces in a
downstream embodiment of the process of this invention using a low pressure
plasma source. Both the generation of activated gas species with a plasma source
and the deagglomeration of the particles require use of substantial quantities of
gas while simultaneously maintaining a sufficiently low pressure. At relatively
modest treatment rates, the low pressure requirement can readily be
accommodated. At higher treatment rates, higher capacity more expensive
vacuum systems are required. It would be desirable to eliminate the need for the
vacuum system by modifying surfaces of deagglomerated organic particles at
atmospheric pressure. Typical equilibrium or thermal plasmas created at
atmospheric pressure exhibit high temperatures which can thermally degrade the
organic particles. Inherently low temperature activated gas species generated by
nonequilibrium atmospheric pressure plasmas sources have been used in the prior
art to modify surfaces of temperature sensitive organic materials without thermal
degradation. Readily agglomerating organic particles can be treated with such
nonequilibrium atmospheric plasma sources when the powders are first
deagglomerated to increase the surface area exposed to the activated species. This
process can be accomplished by either of two alternate embodiments: by treating
the deagglomerated particles downstream from the plasma source employing the
apparatus depicted in Figure 8, or passing the deagglomerated particles directly
through the source, employing the apparatus of Figure 9.

Figure 8 depicts an atmospheric pressure process using a dielectric
barrier discharge source, 540, similar to that known in the prior art, to create
activated species for treating particulates in a reaction chamber, 20, downstream

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from the plasma source. The plasma source, 540, may be comprised of a power

supply, 540S, electrodes, 542 and 544, which are covered or coated with dielectric

layers, 542D, 544D. In accordance with this embodiment, the particulates are first

deagglomerated by feeder assembly, 50'', which incorporates the deagglomeration

5   module 500, described in conjunction with Figure 7. Feeder assembly, 50'',

comprises a bin, 604, a rotary valve, 606, which feeds particulates from the bin,

604, into a hopper, 608. Rotary valve, 606, permits the chamber, 608, to be

maintained at up to two atmospheres of pressure. Gas from a source, 550, being

supplied to deagglomeration module, 500, permeates the particulate material,

10   which only partially fills the screw feeder, 306, to pressurize the hopper, 608. If

desired, process gas can be supplied from source, 550, through valve, 553, directly

to hopper, 608, to maintain hopper, 608, at the same pressure as deagglomeration

module, 500. A mixer, 630, which can take any convenient form, is provided to

insure a steady flow of particles to the screw feeder, 306. In this embodiment

15   which operates at atmospheric pressure, the vacuum pump, 90, may be replaced

with a exhaust fan, 90'.

            An optional diffusion plate, 548, similar to diffusion plate, 48,

described in conjunction with Figure 5, can be used to prevent the particulates

from entering the plasma source, 540. A source, 560, of either a single process

20   gas (when long lifetime activated species are generated) or a gas mixture (when

short lifetime activated species are generated) can be used, as previously

discussed. In the downstream approach the plasma gas is activated by passing it

through a nonequilibrium low temperature plasma source, such as a dielectric

barrier discharge, thus creating plasma-activated species capable of modifying the

25   surface of deagglomerated organic particles without irreversible thermal

degradation of the particles. In this embodiment, plasma-activated species created

in the source are utilized downstream in a separate reaction zone. For long-lived

species, a single gas can be fed to the plasma source for creation of activated

species. Ozone, an example of a species that is stable at atmospheric pressure

30   near room temperature, can be created by disassociating molecular oxygen via

silent discharge in a dielectric barrier discharge plasma source. When activation

of a particular process gas produces short lifetime activated species, a mixture of

gases can be used to assure the presence of activated species in the downstream reaction zone. Many plasma-activated species, like those arising from carbon dioxide (CO_2), have relatively short lifetimes at atmospheric pressure and will not survive long enough to be useful in the downstream embodiment. If diluted with

5 a gas having a sufficiently high energy metastable state, such as helium, the process gas maintains sufficient activity to be useful in the downstream embodiment.

It is believed that the diluting gas reduces the probability of recombination collisions of the activated species. The metastable states of the

10 diluting gas can release energy in the reaction zone thus creating additional activated species. As an example of the downstream embodiment, the surface of a red pigment, such as diketo-pyrrolopyrrole red (DPP red), can be modified at atmospheric pressure using a dielectric barrier discharge, by introducing either pure oxygen or a mixture of oxygen and helium or a mixture of CO_2 and helium

15 into the plasma source. By using appropriate power and voltage to activate the plasma, an activated gas species of sufficiently low temperature can be introduced into the reaction chamber.

Deagglomerated DPP red pigment particles can be introduced into the reaction chamber and exposed to activated species. Surface modification

20 without thermal degradation of the particles can occur prior to substantial reagglomeration of the particles. In this embodiment, the pigment can be kept out of the plasma-activation region by sufficient plasma gas flow rate and/or use of diffusion plates.

Figure 9 depicts an atmospheric pressure process using a dielectric

25 barrier discharge source, 640, similar to that known in the prior art, to create activated species for treating particulates in a reaction chamber, 620, within the plasma source, 640. In accordance with this intrasource embodiment, the particulates are first deagglomerated as described in conjunction with Figure 8 by feeder assembly, 50'', which incorporates the deagglomeration module, 500. In

30 this embodiment a source, 550, of carrier gas feeds the deagglomeration module, 500, through valve, 552. If desired, process gas can be supplied from source, 550, through valve, 553, to hopper, 608, to maintain the hopper, 608, at the same

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pressure as deagglomeration module, 500. As shown, the carrier gas also serves
as the process gas. Optionally, a source, 560, of additional process gas may be
provided as shown. Valves, 556 and 558, may be provided to control flow of the
additional process gas. The plasma source, 640, may be comprised of a power

5   supply, 640S, electrodes, 642 and 644, which are covered or coated with dielectric
layers 642D, 644D. An optional electrode positioning apparatus, 646, and an
optional electrode cooling arrangement, 648, such water cooling, may be provided
as shown. When the level of the particles in the bottom volume, 620V, of the
reaction chamber, 620, has reached a predetermined level an emptying cycle can

10   be initiated, as previously described in conjunction with Figure 7.

        In the typical intrasource embodiment of Figure 9, it is also
possible to pass the deagglomerated organic particles directly through a
nonequilibrium low temperature plasma source to modify the surface of the
particles with the activated species. In this embodiment, the deagglomerated

15   particles pass through the plasma creation region thus exposing substantially
increased surface area for modification. A dielectric barrier discharge is one type
of nonequilibrium plasma source which can be employed for species activation.
Since plasma gas is continuously activated within the source, species lifetimes are
less important than with the downstream configuration. In the intrasource

20   embodiment, either a single feed gas or a mixture of gases can be used. Blending
the feed gas with increasing amounts of a gas such as helium causes the silent
discharge within the plasma creation volume to be converted to an atmospheric
pressure glow discharge. The surface modification of the particles occurs
substantially completely within the plasma generation zone but can continue

25   downstream if sufficient gas activity remains prior to substantial reagglomeration
of the organic particles. Energetic electrons and photons generated within the
plasma source can cause additional surface modifications of the particulate
material.

        In a typical intrasource embodiment, the surface of deagglomerated
30   DPP red can be modified by passing the pigment particles through a dielectric
barrier discharge source while simultaneously activating the plasma gas within the
source with an appropriate level of power and voltage. The plasma gas can consist

of only carrier gas or may consist of a mixture of the carrier gas and the additional

process gas, either separately introduced or blended prior to introduction to the

deagglomeration module. The deagglomerated particle surface is modified while

in contact with activated gas species prior to substantial reagglomeration. Either a

5   mixture of oxygen and helium or CO_2 or a mixture of CO_2 and helium can be used

as the plasma gas. Due to the low temperature of the plasma gas, the particle

surface is modified without thermal degradation. Other plasma gases can be

selected depending on the specific particle type, surface modification required,

and suitability of species lifetimes consistent with treating the deagglomerated

10   organic particles entirely intrasource (short lifetime species) or continuing the

treatment downstream of the source (long lifetime species).

Figure 10 illustrates an alternate feeder assembly ,50''', which is

especially useful when feed pressures in excess of two atmospheres are required.

It is believed that the rotary valve arrangement of Figure 8 is unsuitable for such

15   high feed pressures. This feeder assembly, 50''', comprises a two stage "airlock"

arrangement comprising bin, 704, first valve, 706, first hopper, 708, second valve,

706', and second hopper, 708'. If desired, process gas can be supplied from

source, 550, through valve, 553, directly to hopper, 708', to maintain hopper,

708', at the same pressure as deagglomeration module, 500.

20   Figure 11 illustrates the details of a typical embodiment of the

deagglomeration module, 500. As shown in this figure, the deagglomeration

module comprises a mixing chamber, 502, for mixing particulates from screw

feeder, 306, and receiving carrier gas from a source, 550, mechanical stirring

means, 504, a porous plate, 506, an ultrasonic horn, 508, energized by an

25   ultrasonic transducer, 510, powered by a power supply, 512, and an outlet orifice,

514 , wherein the pressure in the mixing chamber, 502, is maintained above the

pressure in the reaction chamber, 20, (or 620 in Figure 9), and wherein the region

immediately adjacent the outlet orifice, 514, is ultrasonically agitated with

sufficient energy to prevent plugging of the orifice by the particles and to facilitate

30   deagglomeration of the particles. the pressure differential between chamber. 502,

and the reaction chamber, 20, carries the deagglomerated particles into the

reaction chamber. Particles that readily agglomerate tend to form bridges when

attempts are made to feed the particles through small openings. In the present apparatus, the orifice is kept from clogging by the ultrasonic action both as mechanical motion of the orifice and the sound field near the orifice that keeps particles from sticking together. Deagglomeration of particles tends to occur near

5 the orifice since high density of particles effectively absorbs the ultrasonic energy and blocks the energy from propagating any appreciable distance.

Examples

A simplified description of a batch process for treating pigment particles follows. A red organic pigment was treated by activated gas species in a

10 batch process, using the apparatus of Figure 3, at pigment flow rates up to 23 lbs/hr. A general outline of experimental procedure follows: CO_2 process gas was fed to an ASTeX microwave downstream source which created a low-pressure localized plasma in the high electromagnetic field region.

This highly excited plasma exits the high field region and begins

15 recombination while flowing into the reactor. The red pigment was mixed with CO_2 for injection into the reactor volume. Pigment from a hopper was conveyed via carrier gas through a transfer-line into the reactor volume where the resulting pigment/gas mixture contacted the activated gas species thus modifying the pigment surface. Treated pigment product was separated from process gas and

20 collected.

Example 1

A red pigment having Chemical Abstract No. 84632-65-5 (Ciba-Geigy) and the chemical formula, pyrrolo (3,4-C) pyrrol-1, 4-dione 3,6-bis(4-chlorophenyl)-2, 5-dihydro-(9Cl) and having a primary particle size of about 0.6

25 micron, was treated at subatmospheric pressure, using the batch process apparatus of Figure 3, as follows to improve rheology, gloss, and tinting strength while maintaining color within an acceptable range of a paint composition incorporating this pigment.

Plasma-Activation Process Conditions:

30   System pressure, 1.9 Torr

Pigment Feed Rate, 1.2 lbs/hr

Carrier gas CO_2, 2 1/min

Process gas CO$_2$,5 l/min

Microwave Power, 400W

Paint Composition:

1. Solvent blend, 35.84 wt.%
    (71.25% of xylene, 23.75% of
    n-butyl acetate and 5.0% of
    p-amyl acetate)

2. Acrylic polymer dispersant solution 43.83%

3. Pigment, 20.33%

Grinding Procedure After Surface Modification:

The above three ingredients were premixed for 15 minutes, then placed in a beaker grinder using sand media and ground at 350 rpm for 30 minutes, and the sand filtered to produce a color concentrate (dispersion). A Model RVTDCP Brookfield viscometer was used to measure shear viscosity by using #3 spindle, at 1 rpm rotation speed. Gloss measurement was made using a BYK-Gardner, Inc., Haze-Gloss reflectometer at 20 degree and 60 degree angles. Color measurement was made using a MAC colorimeter, by DuPont Engineering Laboratory, Model Series 5 for measuring color at L* (brightness), a* (red-green), b* (blue-yellow). White dispersion for tinting strength (mixing with red dispersion): TiO$_2$ 16.04%, total solid 38.64%.

Product Testing:

Most commonly observed viscosity using the Brookfield viscometer:

	Untreated Pigment	Treated Pigment
Poise	180	20

Gloss was measured by taking sample of the color concentrate and putting it in a #5 drawdown bar from Gardner Co. to produce a film of about 10 microns thick which was air dried for about one hour before measuring the gloss. Gloss measurements:

Observation Angle	Untreated	Treated
20 degrees	7	20
60 degrees	50	63

Color measurement:

Goal with this red pigment was not to alter the color position which was maintained (L*a*b*) to within ±0.3 of the untreated sample. Masstone color batch was prepared as: 86% dispersion, 12% acrylic polymer dispersant solution,

5   and 2% solvent.

This mixture was well mixed in a shaker before spray. Three aluminum panels were sprayed and baked at 125 F for 30 minutes. Color was measured against a red standard by MAC colorimeter. The results were:

Plasma-Treated Sample   dL*=0.61, da*=-0.10, db*=-0.94

10   Untreated Sample   dL*=0.50, da*=+0.17, db*=-1.01 Tinting strength:

Goal was to reach the same shade using less of the pigment. The procedure follows. Take the color concentrate and mix with white dispersion. Mix concentrates for 10 minutes and spray on aluminum panel to hiding. Bake at 125 F in air oven for 30 minutes. Measure color by MAC colorimeter. Delta(L)

15   of treated sample ranged from 0.3 to 0.8 less than untreated. This represented an increase in tinting strength of about 5% or more.

Example 2

Perrindo maroon pigment (a transparent red) having the Chemical Abstract name anthradiisoquinoline-1,3,8,10(2H,9H)-tetrone,2,9- dimethyl-(9C1), having a

20   primary particle size of about 0.2 micron, was treated at subatmospheric pressure, using the batch process apparatus of Figure 2.

Plasma-Activation Process Conditions:

System pressure, 2 Torr

Pigment Feed Rate, 1.7 lbs/hr

25   Carrier gas CO_2, 0.2 l/min

Process gas CO_2, 0.1 l/min

Microwave Power, 400W

Paint Composition:

1.   Solvent blend, 39.66 wt.%

30   (71.25% of xylene, 23.75% of

n-butyl acetate and 5.0% of

p-amyl acetate)

2.   Acrylic polymer dispersant solution 46.43%

3.   Pigment 13.91%

Property Measurement: Relative transparency and absolute haze of drawdown film on Mylar were measured using ColorQuest by HunterLab, Inc.

5 Brookfield viscosity measurement for the dispersion used the same viscometer as used in Example 1. The spindle used was #5 at 1 rpm rotational speed.

Grinding Procedure After Surface Modification:

The 3 ingredients were premixed for 15 minutes. The sample was put in 1 liter 01 attritor and 850 grams of zirconia silicate (0.8 mm) was added. A

10 12 hour grinding period was performed. A sample of the ground mixture was taken each hour, a drawdown on Mylar was made, and relative transparency of the resulting film was measured. Results indicated that the treated sample reached 100% relative transparency after 8 hours of grinding. However, it took 11 hours of grinding for a similar sample containing untreated pigment to reach the same

15 100% relative transparency level.

Product testing

Lowering the viscosity of the sample is believed to be a key to reduced grinding times to achieve 100% relative transparency. After each sample achieved 100% relative transparency, the dispersion was filtered to remove

20 grinding media and viscosity was measured using the Brookfield viscometer. Viscosities were:

	Untreated Pigment	Treated Pigment
Poise	30	4

EXAMPLES 1 to 17

By the methods and apparatuses described herein, the following materials can be treated according to the process of this invention.

Example	Materials	Initial Degradation	Reference*
		Degrees C	
1	diketo-pyrrolopyrrole red pigment	461	c
2	perylene maroon pigment	478	c
3	polybutadiene	325	a
4	polychloroprene	170	a
5	Natural rubber	287	a
6	polyethylene	264	a
7	polypropylene	120	a
8	polyacrylonitirle	235	a
9	polymethacrylic acid	200	a
10	polyvinyl acetate	213	a
11	polyvinyl chloride	200	a
12	cellulose	250	a
13	copper phthalocyanine blue pigment 15:2	460	b
14	polychloro copper phthalocyanine C.l. pigment green 7	480	b
15	quinacridone red pigment	440	b
16	quinacridone violet	310	b
17	copper phthalocyanine blue pigment 15:2	440	c

*- a. Physical Properties of Polymers Handbook. James E. Mark. AIP Press

b. NPIRI Raw Materials Data Handbook. Volume 4 Pigments. National Printing Ink Research Institute.

　　　　　　　　c. Measured by thermal gravimetric analyzer in air at a
temperature gradient of 10 C/min from room temperature to 700 C.

We Claim:

1.   A method for treating the surface of particulate materials that exhibit irreversible thermal degradation when heated above a threshold temperature not exceeding about 500 degrees C with at least one species of plasma-activated process gas in a treatment chamber that contains the plasma source or is downstream of the plasma source, comprising the steps of:

        i   introducing activated process gas into the treatment chamber,

        ii   deagglomerating the particles to expose at least a portion of the surface of substantially each fraction of deagglomerated particles.

        iii   contacting the deagglomerated particle fractions with the activated process gas in the reaction chamber before reagglomeration can occur to any substantial degree,

        iv   modifying at least a portion of the surface of substantially each deagglomerated particle fraction with the activated process gas. and

        v   controlling the temperature of the deagglomerated particle fractions so they do not thermally degrade.

2.   A method according to Claim 1 wherein step iii is carried out at substantially atmospheric pressure in one or both of the following locations: a reaction chamber containing the plasma source and downstream of the plasma source.

3.   A method according to Claim 1 wherein step iii is carried out at substantially subatmospheric pressure in a reaction chamber that is downstream of the plasma source.

4.   A method according to Claim 1 comprising generating the plasma-activated gas introduced into the treatment chamber in step i by a nonequilibrium method selected from the group: low pressure plasmas energized by microwave radiation or by radiofrequency radiation; atmospheric pressure plasmas produced by silent discharge or by glow discharge.

5.   A method according to Claim 1 comprising deagglomerating the particles in a deagglomeration module comprising a mixing chamber for mixing particulates and a carrier gas. a mechanical stirring means. an

ultrasonic horn energized by an ultrasonic transducer, and an outlet orifice,
wherein the region immediately adjacent the outlet orifice is ultrasonically
agitated with sufficient energy to prevent plugging and to effect particle
fractionation.

5   6.   A method according to Claim 1 wherein the particles are
pigment particles maintained below the threshold temperature at which an
observable pigment color shift occurs.

           7.   A method for preparing a color composition using surface-
modified pigment particles comprising the steps:

10   i   disposing to a grinding mechanism agglomerated particles
           that have been surface-modified by the method of Claim 1, and

                  ii   grinding said particles to effect deagglomeration, whereby
           the deagglomeration is effected at less than about 85% of the time it would
           take under identical conditions to deagglomerate pigment particles not

15   surface-modified by the method of Claim 1.

           8.   A color composition comprising surface-treated pigment
particles, the composition having the following properties:

                  i   viscosity less than one-half that of a like composition
           comprising untreated particles of the same pigment,

20   ii   improved tinting strength at least 2% above that of a like
           composition comprising untreated particles of the same pigment, and

                  iii   increased pigment to binder ratio at least about 5% above
           that of a like composition comprising untreated pigment.

           9.   In an apparatus for subatmospheric treatment of particle

25 surfaces comprising a reaction zone in a reaction chamber having particle inlet
and outlet means, a plasma-generating source, and a particle storage hopper that
cooperates with the inlet, the improvement which comprises:

                  i   a particle-filled storage hopper designed to operate at a
   pressure above that of the reaction chamber;

30   ii   a module located between the particle storage hopper and
   the inlet that cooperates with both, the module comprising means for

controlling feed rate of the particles and for deagglomerating the particles, and introducing deagglomerated particles into the reaction zone; and

iii   means for maintaining the deagglomerated particles at a temperature below that at which they thermally degrade.

5   10.   A module for dispersing particles from a storage hopper into a reaction chamber, the reaction chamber being maintained at a lower pressure than the storage hopper, for surface modification by at least one plasma-activated gas species comprising:

i   a mass flow control mechanism for particle transport from
10   the hopper to mechanism ii, and

ii   a mechanism for deagglomerating and dispersing the particles in preparation for their introduction into the reaction chamber.
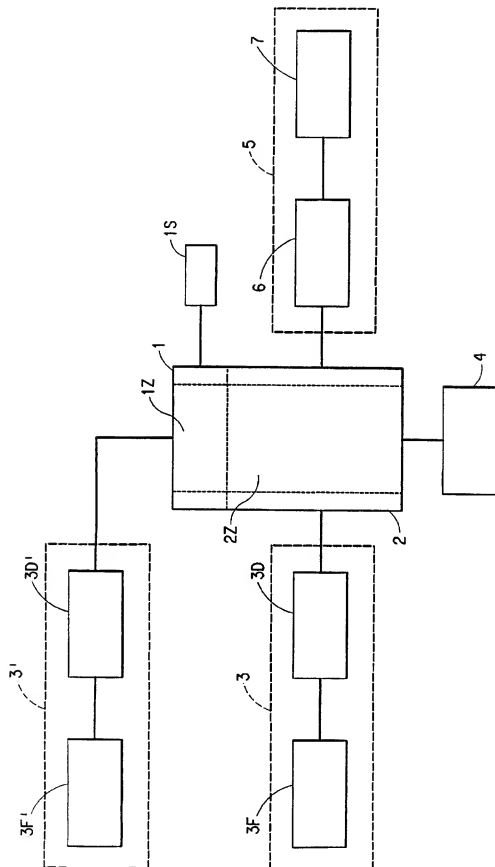
FIG. 1
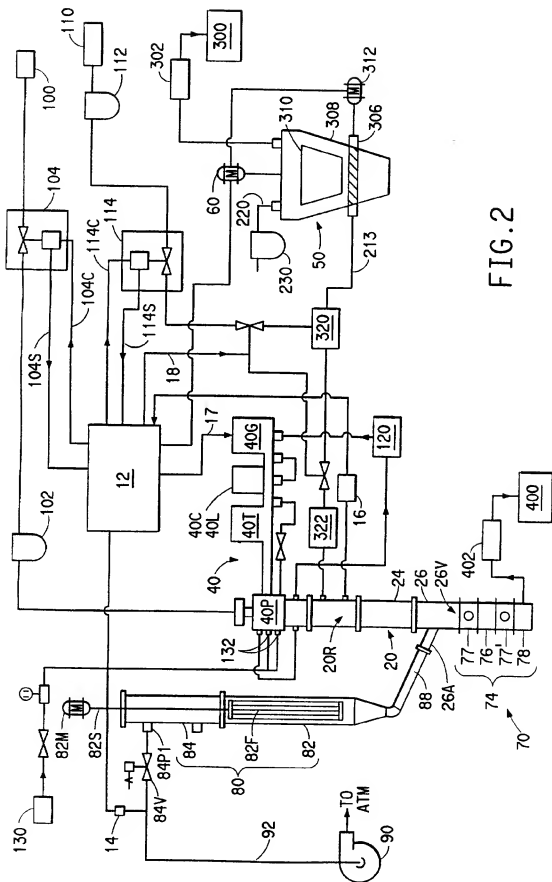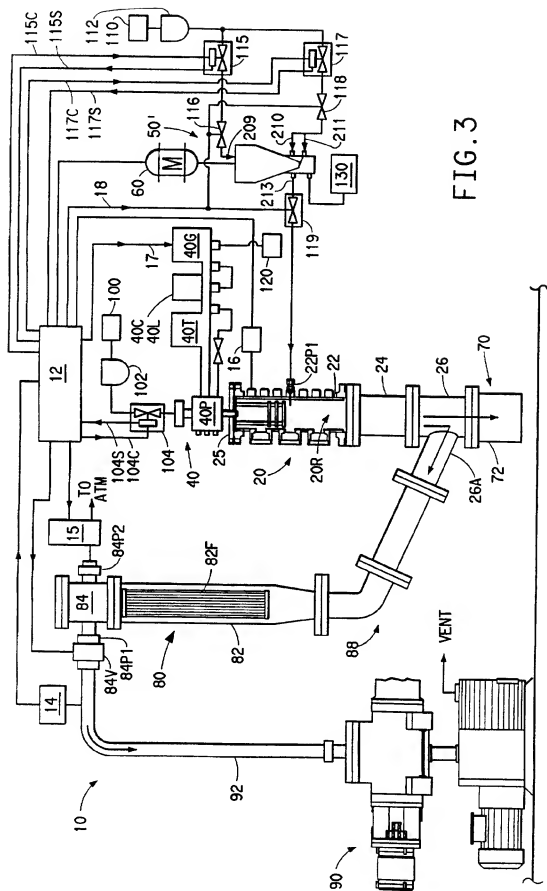
FIG.2
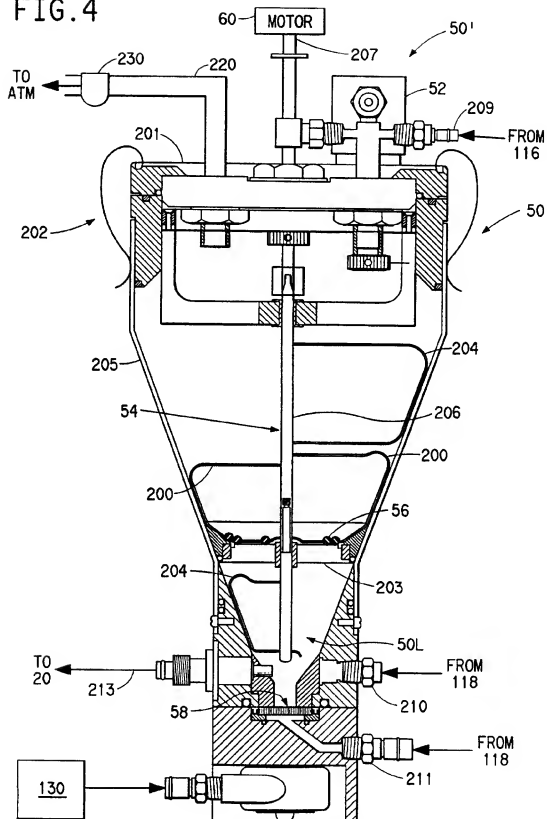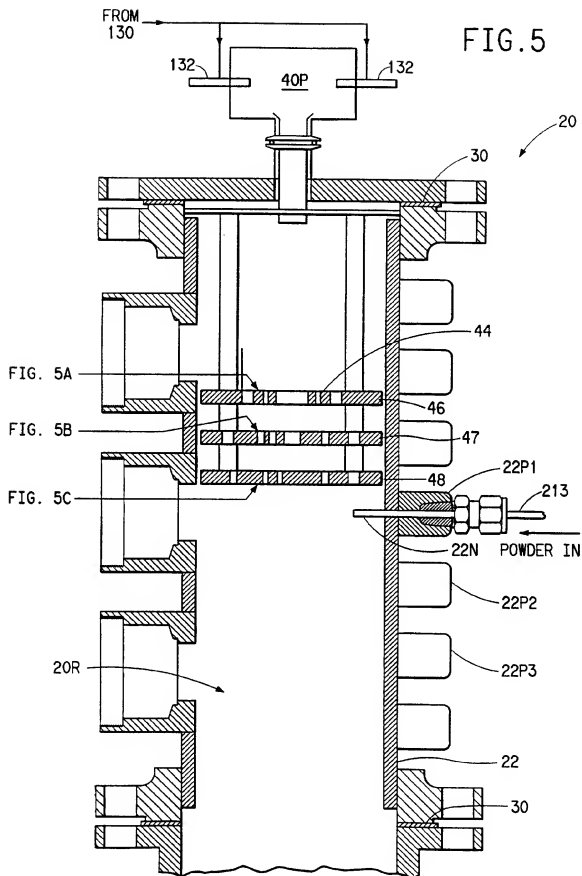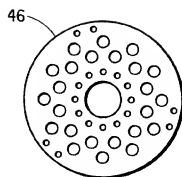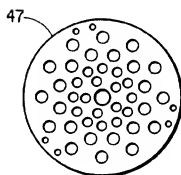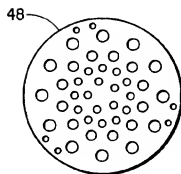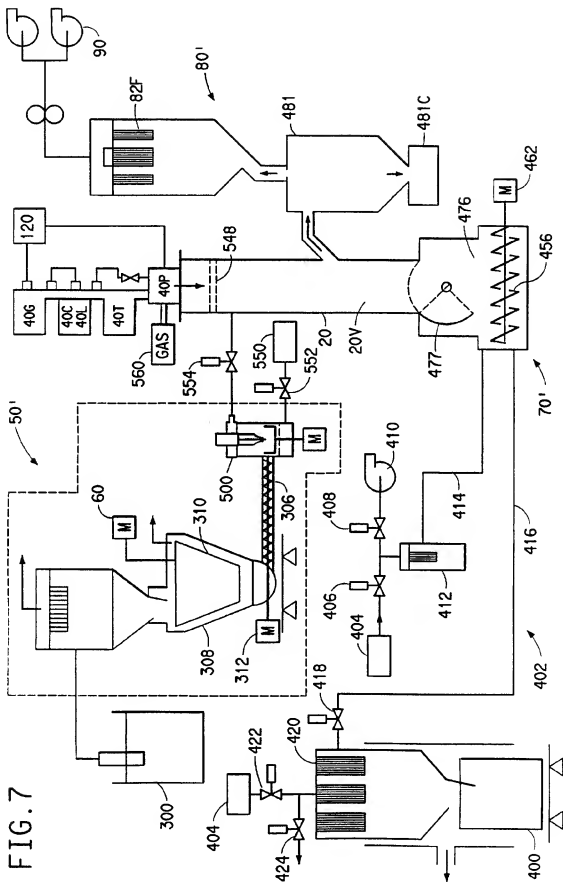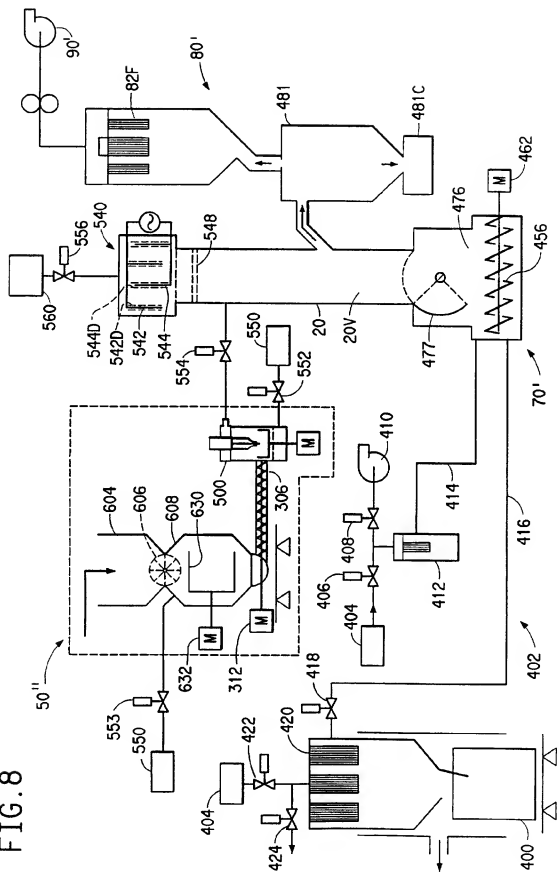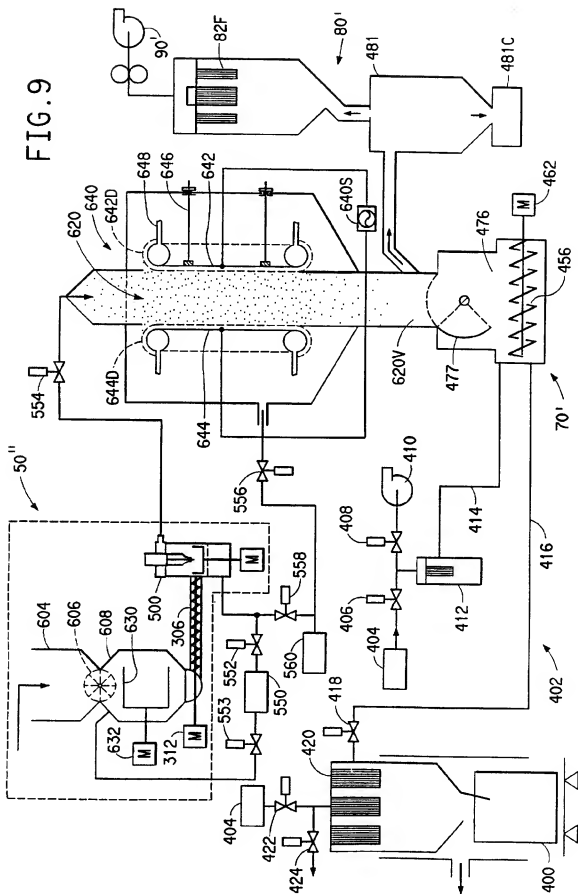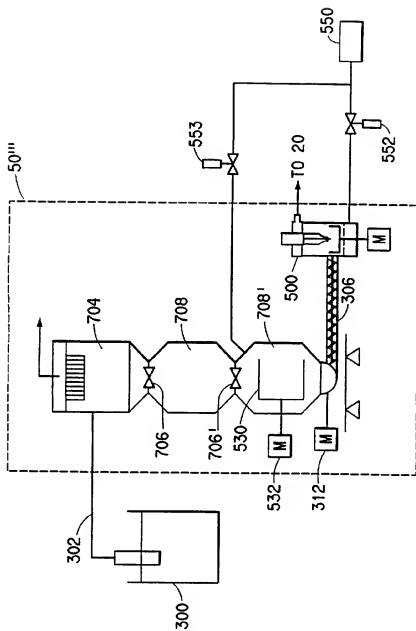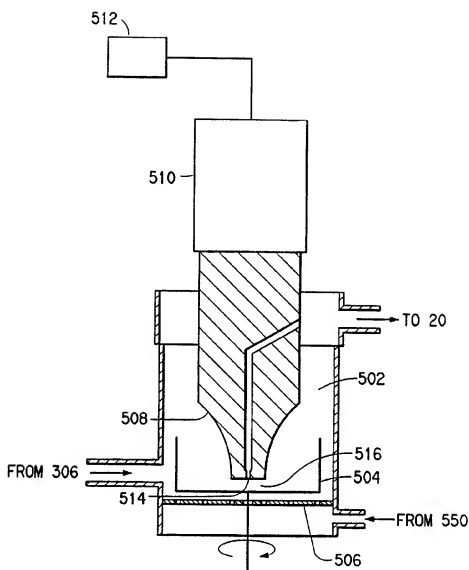
FIG.3

FIG.4

FIG.5

FROM
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132   40P   132

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FIG. 5A

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FIG. 5B   47

FIG. 5C   48

22P1

213

22N   POWDER IN

22P2

20R   22P3

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FIG.6A

FIG.6B

FIG.6C

FIG. 7

FIG.8

FIG.9

FIG.10

FIG.11

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   C09C3/04   C09B67/00   C09D7/12   B01J19/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   C09C   C09B   C09D   B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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☐ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 June 1997	2 7. 06. 97

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